PERFORMANCE OF REINFORCED CONCRETE STRUCTURAL MEMBERS MADE OF ULTRA HIGH PERFORMANCE CONCRETE

A

SYNOPSIS

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CHAPTER-1

INTRODUCTION

1.1 Introduction

With specified durability, tensile ductility, and toughness requirements, Ultra-High Performance Concrete (UHPC) is a cementitious concrete material with a minimum specified compressive strength of 120 MPa. Fibres are typically added to the mixture to achieve the specified requirements. Reactive powder concrete (RPC) is another name for ultra-high performance concrete (UHPC). Portland cement, additional cementitious ingredients, reactive powders, limestone or quartz flour, fine sand, high-range water reducers, and water are commonly used to create the material. It is possible to design the material to have compressive strengths greater than 200 MPa. The thick, smooth surface produced by using fine materials for the matrix is prized for its aesthetics and capacity to accurately transmit form details to the hardened surface. Flexural strengths of at least 48 MPa can be attained when mixed with metal, synthetic, or organic fibres. High carbon steel, PVA, glass, carbon, or a combination of these fibre types or others is frequently used in UHPC. The ability of this material to deform and support flexural and tensile stresses even after initial fracture represents a first for concrete. In applications like closure pours between precast pieces, the high compressive and tensile capabilities of UHPC also provide high bond strength, allowing for shorter embedment lengths of rebar. Because UHPC has high flow characteristics and is self-compacting, some applications don't require the use of reinforcing steel, which simplifies UHPC construction. Because of its high density and little unconnected pore structure, the UHPC matrix has a low permeability (less than 0.02 x 10-12 m^2/s for chloride ion diffusion). Because harmful substances like chlorides can't enter the material because of its low permeability, it has superior durability properties. A few producers have developed pre-mixed UHPC formulations that only require the addition of water. American Society for Testing and Materials (ASTM) has developed ASTM C1856/1856M Standard Practise for Fabricating and Testing Specimens of Ultra High Performance Concrete, which is based on current ASTM test procedures but, these have been modified to be appropriate for UHPC.

Fig: 1 Iowa Boasts First Ultra-High Performance Concrete Highway Bridge in United States

An illustration of the variety of material properties for UHPC is as follows:

Strength

Compressive: 120 to 150 MPa

Flexural: 15 to 25 MPa

Modulus of Elasticity: 45 to 50 GPa

Durability

Freeze/thaw (after 300 cycles): 100%

Salt-scaling (loss of residue): < 0.013 lb/ft3, (< 60 g/m2)

Abrasion (relative volume loss index): 1.7

Oxygen permeability: ($<10^{-20}$ m2)

1.2 Micro structural properties of ultra-high performance concrete

Due to optimised packing density and minimal use of coarse particles, UHPC is more homogeneous than NSC. The unreinforced UHPC is particularly brittle because the size and strength differences between the matrix and the tiny aggregates are so small that, when subjected to external pressure, cracks typically propagate in a straight line. However, UHPC exhibits ductile material behaviour after reinforcement with small or micro fibrous material, and its tensile performance can be greatly enhanced. Three significant factors are responsible for the UHPC's dense microstructure and high material strength. First off, UHPC mixes often

have a very low water to binder ratio. The binder typically consists of cement, silica fume, and additional reactive materials like nano-particles. UHPC matrix has extremely low permeability when the water to binder ratio is low (often 0.25 or below).Other than that, UHPC's packing density has been improved. Cement, quartz powder, and silica fume are all ultrafine particles that are tightly bound together. Besides these, the matrix's free CH combines with highly pozzolanic material like silica fume to generate more calcium silicate hydrate, which results in extremely high compressive strength. For further enhancing the UHPC strength, a volume-based water/ultrafine particles ratio has also been established in addition to the mass-based water/binder ratio. Optimising the packing density is restricted by the practicality of UHPC. The holes between the particles are getting narrower with better/higher packing density, making it difficult for the water to lubricate the particles. Additionally, the surface areas that need to be moistened significantly increase when there are large amounts of ultrafine particles. Additionally, because of their tendency to attract nearby particles to form larger particles, ultrafine particles can no longer function as the best filler due to their inter-particle forces. High-performance super plasticizer may de-agglomerate and liquefy not only the cement but also all other tiny particles, which can resolve these issues.

CHAPTER-2

LITERATURE REVIEW

2.1 Introduction:

Ultra-high-performance concrete (UHPC) is a type of concrete that exhibits exceptional mechanical properties such as high strength, high durability, and high ductility. The use of UHPC in reinforced concrete structural members has gained significant attention due to its potential to enhance the structural performance of concrete structures. The literature review of the performance of reinforced concrete structural members made from UHPC can be divided into the following categories:

1. Mechanical Properties of UHPC: The mechanical properties of UHPC have been extensively studied in the literature. Studies have shown that UHPC has high compressive and tensile strengths, high modulus of elasticity, and excellent durability compared to conventional concrete. High ductility and strain capacity of UHPC make it an ideal material for the design of structural members subjected to high load and deformation.
2. Reinforcement Strategies: Several reinforcement strategies have been proposed for UHPC reinforced concrete structural members to improve their performance. One such strategy is the use of steel fibres in the UHPC mix, which enhances the bond between the concrete and steel reinforcement, resulting in improved structural behaviour. Another strategy is the use of pre-stressed reinforcement in UHPC members to control cracking and improve the load carrying capacity of the structure.
3. Performance Evaluation of UHPC Members: Numerous studies have evaluated the performance of UHPC reinforced concrete members under different loading conditions. These studies have shown that UHPC exhibit improved structural behaviour, such as higher load carrying capacity, enhanced ductility, and reduced cracking, compared to conventional concrete members. Additionally, UHPC members have shown to have high resistance to environmental factors such as freeze-thaw cycles, chloride ingress, and carbonation.
4. Structural Applications of UHPC: The use of UHPC in structural applications has gained significant attention in recent years due to its superior properties. UHPC has been used in the design of bridge decks, beams, columns, and other structural members, resulting in structures with enhanced performance, increased durability, and reduced life-cycle costs.

2.2 Literature

In 2022, Rui Yu et al study's objective was to suggest a design and optimisation strategy for creating Ultra-High Performance Concrete (UHPC) with quick-setting and quick-hardening properties. First, an optimised cementitious mixture made primarily of alumina cement and gypsum is produced using the response surface methodology. The particle dense packing skeleton of UHPC is then created using the particle dense packing model. The impact of water and steel fibre is then studied. According to the acquired experimental results, the 3 hour strength develops the fastest, reaching 55 MPa, when the gypsum substitution is 15%, while the later strength may be constantly increased to 81 MPa after 7 days. Additionally, 2.5% (by volume) steel fibre can increase the 3 h and 28 d compressive strength of the newly developed UHPC by 157.0% and 46.1%, respectively, in comparison to the reference group without fibre. The created UHPC generally has advanced mechanical qualities and durability both at super early stages and later stages, which is promising in the field of quick building repair.

In 2021,Khazaee et. al. studied experimental evaluation of dowel action in ultra-high performance concrete with various tests and to deal with solution an experimental program was developed to identify the cracked surface behavior under shear loading.

In 2021,Yanping Zhu et. al, studied that in comparison to normal strength concrete (NSC), ultra-high-performance concrete (UHPC) has great tensile strength, compressive strength, and durability. In contrast to NSC and high strength concrete (HSC), UHPC may be less resistant to spalling under high temperatures and fire conditions due to its high compactness, low permeability, and lack of capillary holes. Few investigations have been conducted on the UHPC in high temperature and fire loading applications for both materials and structures. Although there are still some such as the processes for NSC and HSC may not be appropriate for understanding the complex behaviour of UHPC at high temperatures with spalling behaviour since UHPC contains a variety of constituents and high strengths. This paper evaluates recent developments in the behaviour of UHPC at high temperatures. Based on the current knowledge, some methods for improving the high-temperature performance of UHPC are recommended.

In 2020,Wazeer et. al., studied various design mixtures and they were tested in an effort to create ultra-high performance concrete (UHPC). Six mixes (scenarios) with the goal of creating ultra-high performance concrete were created. At initial, one typical combination

was developed. The mix elements (materials), additives, and curing time were altered to create the six situations. Twenty one specimens (cubes, three cubes of each mix) were created and tested. The specimens were tested 7, 14, and 28 days after curing in order to track the development of the compressive strength. Curing was carried out in both hot (35+/-2) and cool (20+/-2) water. Then, each scenario's attributes were contrasted with the baseline characteristics. He concluded that compressive strength increased in nearly every circumstance. The strength increased to varying degrees as a result of modifications to the components, curing temperature, and curing time. The increase in strength for the materials and additives is on the order of 43 MPa on average. The average increase in strength throughout the curing process is 17 MPa. The strength increases by an average of 6 MPa regardless of the water's temperature used for curing.

In 2020,Ye Li et. al examined how well a hybrid ultra-high performance concrete reinforced with steel fibres flexes. On the load-deflection curves, toughness, and toughness index of UHPFRC, the effects of various levels of fibre hybridization, aggregate size, water-to-binder ratio, and exposure temperature are investigated. Results concluded that a hybrid blend of steel and polyethylene (PE) fibres significantly improved the limit of proportionality, rupture modulus, toughness, and toughness index of UHPFRC. The current study's UHPFRC with 0.5 vol% PE and 2.0 vol% steel fibres exhibits the greatest flexural performance. The flexural performance of UHPFRC is decreased by a higher water-to-binder ratio and a smaller aggregate. PE fibres have very little impact on spalling prevention compared to polypropylene (PP) fibres. After being exposed to high temperatures, the flexural performance of PE-steel hybrid UHPFRC is drastically decreased.

In 2020,Srishti Banerji et.at studied the behaviour of ultra high performance fibre reinforced concrete (UHPFRC) beams exposed to the combined effects of structural loads and fire exposure, the findings of which are presented in this work. To assess the structural behaviour and spalling performance under ambient and fire conditions, five large-scale UHPFRC beams that were manufactured with various batch mix proportions underwent testing. This results in lower fire resistance. Higher fire resistance results from the presence of polypropylene fibres in UHPFRC, which reduces the extent of fire-induced spalling. UHPFRC beams with higher loads have less spalling and are better able to release pore pressure by tensile cracking. Additionally, UHPFRC beams made of polypropylene fibre perform better in design fire situations with a clear cooling phase than in fire scenarios without a decay phase.

In 2020, Zhang, W. et.al. presented review on the structural behaviour of ultra-high-performance concrete: Material properties, structural members, and connections.

In 2020, Ma H. et.al. Presented A review of structural performance of ultra-high performance concrete with comparison of various results in various stages based on the behaviour of materials tested.

In 2019, Ren et. al. presented his design and studied the structural behaviour to analyze its feasibility with a super-long span. He concluded his results with calculations and number based on quantity and quality.

In 2019, K. M. A., Al-Ahmed et. al. presented A comprehensive review on the mechanical Properties of ultra-high-performance fiber-reinforced concrete (UHPFRC).

In 2018, Chengqing Wu et. al. briefly reviewed the historical evolution of UHPC and found the impact of each and every one of its material components. Conclusion leads to study that High pozzolanic material content is a defining characteristic of UHPC. The impact of adding nonmaterial's in addition to the silica fume. The use of UHPC in protective constructions against blast loads is discussed and the scant test data in the public literature supported UHPC's blast resistant property.

In 2018, Wu et. al. presented a systematic investigation on UHPC-filled double-skin tubes subjected to close-range blast loading.

In 2018, Denarié, E. et. al. described State-of-the-art review on ultra-high performance fibre-reinforced concrete (UHPFRC): A promising material for the concrete industry. The paper dealt with UHPFRC and its results.

In 2017, Singh et. al. investigated the efficacy of the hybrid approach for validating the existing concrete model, behaviour of large-scale structural members made up of UHPFRC was further studied.

In 2017, Xiong et. al. was motivated by increasingly prevalent use of high strength steel and concrete materials in high-rise buildings to achieve better structural performance with less material usage.

In 2017, Habel, K. et. al reviewed Structural behaviour of ultra-high-performance fiber-reinforced concrete (UHPFRC):

In 2017, Nematollahi, B. et. al discussed in research review about the Performance of ultra-high-performance fibre-reinforced concrete.

In 2017, Wille, K. et. al presented review of the mechanical properties of ultra-high-performance fibre-reinforced concrete (UHPFRC).

In 2017, Han et. al. study's aim was to reduce production costs for UHPFRC members by using a bundle of longitudinal reinforcement bars as a substitute for steel fiber. Multiple tests and results were conducted and concluded in study.

In 2017, Kim et. al. developed an optimal structural system for the hybrid cable-stayed bridge expected to have a durable lifetime of 200 years and of which major structural members are made of ultra high performance concrete (UHPC) with 200 MPa-class compressive strength.

In 2013, Soroushian, P. et. al. discussed about Ultra-High Performance Concrete (UHPC) and their behaviour when subjected to multiple materials.

In 2012, Larrard, F. et. al. presented a report on Mix design for Ultra-High Performance Concrete UHPC and their behaviour when subjected to multiple materials.

In 2011, Aïtcin, P. C. Studied High-Performance Concrete and its properties with different kind of compensator materials.

In 2009, (Rauch et. al. based his study on the conception of reinforced uhpc structural elements. An analytical model is presented which enables the calculation of the cracking and deformation behaviour of reinforced UHPFRC structural elements.

In 2007, Larrard F. discussed about the Mechanical behaviour of ultra-high-performance concrete. This paper concluded the theoretical knowledge with some data study with various other materials.

In 2006, Graybar, B. A. examines material property characterization of ultra-high performance concrete.

In 2004, Li, V. C. designed UHPFRC mix for improved structural performance.

2.3 Findings from Literature Review (Identification of Gaps)

The research gap in the performance of reinforced concrete members made of ultra-high-performance concrete (UHPC) refers to areas within the existing body of knowledge where further research is needed. Although UHPC offers exceptional mechanical and durability properties compared to conventional concrete, there are still several aspects that require investigation and improvement. Some potential research gaps in this field include:

1. Structural behaviour: There is a need for a deeper understanding of the structural behaviour and performance of reinforced concrete members made of UHPC. This involves investigating load-carrying capacity, flexural and shear behaviour, bond strength between reinforcement and UHPC, and the influence of different reinforcement configurations.

2. Durability: While UHPC is known for its superior durability properties, further research is necessary to assess long-term performance under various environmental conditions. This includes investigating the effects of exposure to aggressive chemicals, freeze-thaw cycles, and carbonation on the durability and service life of UHPC members.
3. Construction techniques: UHPC's unique properties may require innovative construction techniques or modifications to existing practices. Research is needed to explore efficient and practical methods for casting, placing, and curing UHPC in real-world construction scenarios. This involves investigating issues such as workability, formwork removal time, and appropriate curing regimes.
4. Cost-effectiveness: UHPC is generally more expensive than conventional concrete, which limits its widespread adoption. Research is needed to explore cost-effective mix designs, potential material substitutions, and optimization of production processes to reduce the overall cost of UHPC members without compromising their performance.
5. Standardization and design guidelines: Currently, there is a lack of standardized design guidelines and codes specific to UHPC members. Further research is required to develop comprehensive design guidelines that consider the unique properties and behavior of UHPC, including load and resistance factor design (LRFD) provisions, serviceability criteria, and detailing requirements for reinforcement.
6. Sustainability and environmental impact: While UHPC offers potential benefits in terms of reduced material usage and longer service life, the overall sustainability and environmental impact of UHPC members need to be assessed. Research is required to evaluate the life cycle assessment (LCA) and carbon footprint of UHPC production, as well as the potential for incorporating recycled or supplementary cementitious materials to enhance sustainability.

Based on the identified research gaps in the performance of reinforced concrete members made of ultra-high-performance concrete (UHPC), the following objectives can be formulated:

1. To optimize the design and performance of UHPC.
2. To investigate the structural behaviour of UHPC
3. To Assess durability performance of UHPC
4. To develop construction techniques for casting, placing, and curing UHPC considering factors such as workability, formwork removal time, and appropriate curing regimes.
5. To enhance cost-effectiveness of UHPC without compromising their performance.
6. To Evaluate sustainability and environmental impact for incorporating recycled or supplementary cementitious materials

7. To develop an analytical model/ correlation for prediction of strength and durability properties of UHPC.

2.4 Scope of Research

Research will be carried out to study the strength and durability properties of UHPC samples made with various combinations.

CHAPTER-3

RESEARCH METHODOLOGY

3.1 Research Methodology

The systematic approach to bridge the gap as identified from the literature survey shall be followed. The detailed properties of UHPC shall be studied. The methodology shall consist of following steps for proposed project. Step by step methodology of the proposed work to address the objectives outlined for the performance of reinforced concrete members made of ultra-high-performance concrete (UHPC) as follows:

3.2 Investigate the structural behaviour:

- **Experimental testing:** Conducting laboratory experiments to evaluate the load-carrying capacity, flexural and shear behaviour of UHPC members through various tests such as bending tests, shear tests, and bond tests.
- **Non-destructive testing:** Utilizing non-destructive testing techniques such as ultrasound, acoustic emission, or digital image correlation to monitor and assess the structural behaviour of UHPC members under different loading conditions.
- **Finite element analysis:** Developing numerical models using finite element analysis to simulate and analyze the structural behaviour of UHPC members, considering material properties, reinforcement configurations, and loading conditions.

3.3 Assess durability performance:

- **Accelerated aging tests:** UHPC specimens can be used to accelerate aging tests that simulate real-world environmental conditions, including exposure to aggressive chemicals, freeze-thaw cycles, and carbonation, and monitor the degradation over time.
- **Durability modelling:** Developing predictive models based on experimental data and theoretical considerations to estimate the long-term durability performance of UHPC members under specific environmental exposures.
- **Field exposure studies:** Conducting long-term monitoring of UHPC members installed in real-world environments to assess their durability performance over an extended period.

3.4 Develop construction techniques:

- **Formwork optimization:** Investigating different formwork materials and surface treatments to achieve the desired workability and surface finish of UHPC members.

- **Curing strategies:** Study of different curing methods, including steam curing, moist curing, and self-curing mechanisms, to determine the most effective curing regime for UHPC members in terms of strength development and durability.
- **Casting and placement techniques:** Exploring innovative casting and placement techniques, such as self-compacting concrete or precast/prestressed UHPC elements, to improve efficiency and quality in UHPC member construction.

3.5 Enhance cost-effectiveness:

- **Mix design optimization:** Conduct laboratory experiments to optimize the mix design of UHPC by adjusting the proportions of constituent materials, including cementitious materials, aggregates, and additives, to achieve the desired performance while reducing costs.
- **Material substitution:** Investigate the potential of using alternative materials, such as recycled aggregates or supplementary cementitious materials, to replace or partially substitute conventional materials in UHPC mixtures, considering their effect on performance and cost.
- **Production process optimization:** Analyze and optimize the production processes for UHPC members, including batching, mixing, casting and curing to improve efficiency and reduce costs without compromising performance.

3.6 Evaluate sustainability and environmental impact:

- Life cycle assessment (LCA): Conduct a detailed LCA study to evaluate the environmental impact of UHPC production, considering all stages from raw material extraction to end-of-life disposal, and compare it with conventional concrete to assess the sustainability benefits of UHPC.
- Material characterization: Analyze the properties and behaviour of recycled or supplementary cementitious materials that can be incorporated into UHPC mixtures, considering their availability, performance, and environmental benefits.

3.7 General Steps to conduct laboratory experiments to evaluate the load-carrying capacity, flexural and shear behaviour of UHPC members:

1. **Specimen preparation:**

- Determine the size and shape of the UHPC specimens based on the specific requirements of the tests (e.g., bending, shear, or bond).
- Prepare the molds or formwork to cast the UHPC specimens according to the desired dimensions and configurations.
- Mix the UHPC ingredients in the laboratory, ensuring proper proportioning and mixing procedures to achieve the desired UHPC properties.

2. **Casting and curing:**

- Pour the UHPC mixture into the prepared moulds or formwork, taking special care so to avoid segregation and air voids.
- Consolidate the UHPC using appropriate vibration techniques to ensure proper compaction.
- Place reinforcement (if applicable) in the UHPC specimen according to the desired reinforcement configuration.
- Apply appropriate curing conditions to facilitate the development of UHPC strength and durability. This may involve moist curing, thermal curing, or a combination of both, depending on the specific requirements.

3. Testing setup:

- After the UHPC specimens have achieved sufficient strength, carefully demold them and prepare them for testing.
- Determine the appropriate testing setup and equipment based on the specific tests to be conducted (bending, shear, or bond).
- Install the UHPC specimens in the testing apparatus, ensuring proper alignment and support to simulate the intended loading conditions accurately.

4. Bending tests:

- Apply a gradually increasing load at the centre of the UHPC specimen until failure occurs or the desired load level is reached.
- Record the applied load and the corresponding deflection throughout the test.
- Calculate and analyze parameters such as load-deflection behaviour, ultimate load capacity, flexural stiffness, and cracking patterns.

5. Shear tests:

- Apply a shear load to the UHPC specimen until failure or the desired load level is reached.
- Record the applied load and the corresponding shear displacement or deformation throughout the test.
- Calculate and analyze parameters such as load-displacement/shear deformation behaviour, ultimate shear capacity, and shear stress distribution.

6. Bond tests:

- Prepare two UHPC specimens with embedded reinforcement, such as steel bars or fibers.
- Apply a tensile or pull-out force to one end of the embedded reinforcement while the other end is fixed.
- Measure and record the applied load and the corresponding displacement or slip of the reinforcement.

- Calculate and analyze parameters such as bond strength, bond-slip behaviour, and failure modes.

7. **Data analysis and interpretation:**

- Analyze the data obtained from the tests, including load-displacement/deformation curves, failure modes, and any other relevant observations.
- Compare the results with the expected behaviour of UHPC members and relevant design criteria or standards.
- Draw conclusions regarding the load-carrying capacity, flexural and shear behaviour, and bond performance of the UHPC members based on the experimental findings.

3.8 To assess the durability performance of UHPC members, It includes study of the resistance to aggressive chemicals, freeze-thaw cycles, and carbonation. The following methodologies can be employed:

1. **Accelerated aging tests:**

- **Design of test specimens:** Prepare UHPC specimens in the desired shapes and sizes, considering the intended environmental exposures. For chemical exposure, prepare specimens with appropriate exposure surfaces (e.g., immersed in chemical solutions or subjected to chemical sprays). For freeze-thaw and carbonation exposure, prepare specimens with adequate reinforcement and proper exposure conditions.
- **Environmental exposure simulation:** Subject the UHPC specimens to accelerated aging conditions that simulate real-world environmental exposures. This may involve immersing specimens in aggressive chemical solutions, cycling them between freezing and thawing conditions or exposing them to elevated carbon dioxide levels.
- **Monitoring and evaluation:** Monitor the specimens over time to assess their durability performance. This includes measuring properties such as mass loss, dimensional changes, surface deterioration, and mechanical strength degradation. Regular intervals of data collection will allow for the observation of degradation trends and the determination of durability performance under accelerated conditions.

2. **Durability modelling:**

- **Experimental data collection:** Conduct a series of laboratory tests to gather experimental data on the performance of UHPC specimens exposed to different environmental conditions. This may involve subjecting specimens to specific chemical solutions, freeze-thaw cycles or accelerated carbonation tests while collecting relevant data.
- **Model development:** Based on the experimental data collected, develop predictive models that estimate the long-term durability performance of UHPC members under specific

environmental exposures. These models can incorporate degradation mechanisms, material properties, exposure conditions and other relevant factors.

- **Model validation:** Validate the developed models by comparing their predictions with experimental data from independent tests or long-term field exposures. This validation process ensures the accuracy and reliability of the models in estimating the durability performance of UHPC members.

3. **Field exposure studies:**

- Selection of field sites: Identify and select suitable field sites where UHPC members have been installed and exposed to real-world environmental conditions. These sites should represent different exposure scenarios and cover a range of UHPC applications (e.g., bridges, marine structures, and infrastructure).
- **Long-term monitoring:** Conduct regular inspections and measurements on the field-exposed UHPC members to assess their durability performance over an extended period. This may involve visual inspections, non-destructive testing, and material sampling for laboratory analysis.
- **Data analysis:** Analyze the collected data to evaluate the degradation mechanisms, identify any patterns or trends in performance, and assess the long-term durability of UHPC members in the field. This analysis can provide insights into the effectiveness of UHPC in real-world environments and guide future improvements in design and construction practices.

3.10 To develop construction techniques for UHPC members, specifically focusing on formwork optimization, curing strategies, and casting and placement techniques, the following methodologies can be employed:

1. **Formwork optimization:**

- **Material selection:** Investigate different formwork materials such as plywood, steel, or plastic to assess their suitability for UHPC casting. Evaluate factors such as ease of use, dimensional stability, and resistance to UHPC's high early-age strength.
- **Surface treatments:** Experiment with various surface treatments such as form release agents, coatings, or liners to achieve the desired workability and surface finish of UHPC members. Evaluate the impact of these treatments on formwork removal time, surface aesthetics, and adhesion properties.
- **Formwork design and configuration:** Study different formwork designs and configurations to optimize formwork geometry, minimize joint lines, and improve overall constructability. This may involve exploring modular formwork systems or custom formwork solutions tailored to UHPC member shapes.

2. **Curing strategies:**

- Moist curing: Study different moist curing methods, including water spraying, covering with wet burlap or geotextile, or using moist curing compounds. Evaluate their effectiveness in maintaining moisture levels and promoting UHPC hydration and strength gain.

3. **Casting and placement techniques:**

- **Self-compacting concrete (SCC):** Investigate the feasibility and performance of SCC for UHPC casting. Develop UHPC mixtures with optimized rheological properties, including viscosity, flowability, and passing ability, to achieve self-consolidation without the need for excessive vibration.
- **Precast/prestressed elements:** Explore the use of precast or prestressed UHPC elements to improve construction efficiency and quality. Investigate the fabrication processes, pre-stressing methods, and connection details specific to UHPC members, ensuring compatibility with UHPC's unique properties.
- **Fiber reinforcement strategies:** Study the effect of different fiber reinforcement types (such as steel, glass, or synthetic fibers) and their distribution within UHPC members. Evaluate the impact on casting, placement, and structural performance, including crack control, ductility, and post-cracking behaviour.

For each of these methodologies, it is important to conduct laboratory-scale experiments and if possible field trials to assess their practicality, effectiveness, and compatibility with UHPC. Consider factors such as workability, formwork removal time, curing efficiency, mechanical properties, and constructability when evaluating the performance and suitability of the developed construction techniques.

3.9 To enhance the cost-effectiveness of UHPC, the following methodologies can be employed:

1. **Mix design optimization:**

- **Selection of constituent materials:** Identify the available cementitious materials, aggregates, and additives that can be used in UHPC mixtures. Evaluate their cost, availability, and performance characteristics.
- Experimental testing: Conduct laboratory experiments to optimize the mix design of UHPC by adjusting the proportions of constituent materials. Vary the ratios of cementitious materials, aggregates, and additives to achieve the desired performance while considering cost reduction.
- **Performance assessment:** Evaluate the mechanical properties, durability, and workability of the optimized UHPC mixtures through testing. Compare the performance of these mixtures

with conventional UHPC to ensure that the cost optimization does not compromise the desired characteristics.

2. **Material substitution:**

- Identification of alternative materials: Investigate the potential of using alternative materials, such as recycled aggregates or supplementary cementitious materials (e.g., fly ash, slag), as substitutes or partial replacements for conventional materials in UHPC mixtures. Consider the availability, cost, and environmental benefits of these alternative materials.
- **Experimental characterization:** Conduct laboratory experiments to assess the performance of UHPC mixtures incorporating alternative materials. Evaluate their influence on mechanical properties, durability, and workability. Compare the performance of these mixtures with conventional UHPC to determine their viability.
- **Cost analysis:** Perform a cost analysis to assess the impact of material substitution on the overall cost of UHPC production. Consider factors such as material availability, processing requirements, and potential savings from using alternative materials.

3. **Production process optimization:**

- **Process analysis**: Analyze the entire production process for UHPC members, including batching, mixing, casting, and curing. Identify areas where inefficiencies or unnecessary costs may be present.
- **Process modification**: Optimize the production processes by implementing changes to improve efficiency and reduce costs. This may involve adjustments in batching procedures, mixing techniques, casting methods, and curing regimes. Consider the impact of these modifications on UHPC properties and performance.
- **Performance evaluation**: Conduct testing and analysis to evaluate the performance of UHPC members produced using the optimized production processes. Compare the properties and characteristics of these members with those produced using conventional processes to ensure that the modifications do not compromise performance. It is important to collect data, analyze results, and compare findings to ensure that cost optimization efforts do not compromise the required performance and durability of UHPC members. Collaboration with industry stakeholders, such as material suppliers and contractors, can provide valuable insights and practical considerations for achieving cost-effective UHPC production.

3.10 To establish design guidelines and standards for UHPC members, the following methodologies can be employed:

1. **Literature review and synthesis:**

- Conduct a comprehensive review of existing literature, research papers, design codes, and guidelines related to UHPC member design. Gather information on various aspects, including material properties, structural behaviour, and design methodologies.
- Synthesize the findings from the literature review to identify the current state of knowledge and potential gaps in understanding. Determine areas that require further research and development for establishing design guidelines and standards for UHPC members.

2. **Experimental validation and refinement:**

- Perform experimental testing and analysis on UHPC members to validate and refine design approaches and guidelines. This may involve conducting laboratory-scale tests, such as load tests, to assess the structural behaviour and performance of UHPC members under different loading conditions.
- Evaluate the results of experimental tests and compare them with existing design approaches and guidelines. Identify any discrepancies or areas that need improvement and refinement.
- Use the experimental data to calibrate and validate analytical models and design methodologies specific to UHPC members. This iterative process helps refine the design guidelines and standards.

3. **Collaborative efforts:**

- Engage with industry professionals, researchers, and regulatory bodies to establish consensus-based design guidelines and standards for UHPC members. Collaborative efforts can be facilitated through workshops, conferences, and technical committees dedicated to UHPC research and development.
- Foster discussions and knowledge exchange among stakeholders to gather diverse perspectives and expertise. This collaborative approach helps ensure that the design guidelines and standards reflect a broad consensus within the UHPC community.
- Incorporate feedback and input from experts and practitioners in the field of UHPC to address practical considerations and real-world challenges in the development of design guidelines and standards.
- Regularly update and refine the design guidelines and standards as new research findings and technological advancements emerge.

It is important to consider relevant international standards and codes, such as those provided by organizations like ACI (American Concrete Institute) and fib (International Federation for Structural Concrete), while developing UHPC design guidelines and standards. Collaboration

with industry partners and regulatory authorities will help ensure the practicality and applicability of the guidelines and standards in real-world projects.

3.11 To evaluate the sustainability and environmental impact of UHPC, the following methodologies can be employed:

1. **Life cycle assessment (LCA):**

- Scope definition: Define the boundaries of the LCA study, including the life cycle stages to be considered, such as raw material extraction, production, transportation, use, and end-of-life disposal of UHPC.
- **Data collection:** Gather data on energy consumption, material inputs, emissions, and waste generation associated with each stage of the UHPC life cycle. This may involve collecting data from suppliers, conducting surveys, or using industry databases.
- Impact assessment: Analyze the collected data using appropriate impact assessment methods to quantify the environmental impacts of UHPC production and use. Consider categories such as greenhouse gas emissions, energy consumption, water usage, and waste generation.
- **Comparison with conventional concrete:** Compare the results of the UHPC LCA with those of conventional concrete to assess the sustainability benefits of UHPC. Identify the potential areas where UHPC outperforms conventional concrete and areas that require further improvement.

2. **Material characterization:**

- **Recycled materials:** Investigate the potential of incorporating recycled materials, such as recycled aggregates or supplementary cementitious materials (e.g., fly ash, slag), into UHPC mixtures. Assess the availability and suitability of these materials and analyze their impact on UHPC performance and environmental benefits.
- **Performance analysis:** Conduct laboratory testing and analysis to evaluate the properties and behaviour of UHPC mixtures incorporating recycled or supplementary cementitious materials. Assess their impact on mechanical properties, durability, and workability of UHPC.
- **Environmental benefits assessment:** Evaluate the environmental benefits associated with the use of recycled or supplementary cementitious materials in UHPC mixtures. This may involve comparing the environmental impacts of UHPC with and without these materials and quantifying the potential reductions in resource consumption, waste generation, and emissions.

Throughout these methodologies, it is important to consider the broader environmental, social, and economic aspects of sustainability. Collaborate with experts in the field of sustainability assessment and engage with stakeholders such as sustainability consultants, researchers, and regulatory bodies to ensure comprehensive and robust evaluations of UHPC's sustainability and environmental impact.

CHAPTER-4

PROCEDURE

4.1 ACTIVITY PLAN

Activity Plan								
Activity	Time in months							
	3	6	9	12	15	18	21	24

Literature survey								
Procurement of raw material								
Raw material characterization								
Identifying Properties of the materials								
Casting of cubes and beams								
Fabrication of Experimental Setup & Experimentation								
Conducting Laboratory Investigations								
Analytical Investigations and data correlation								
Report preparation								
Thesis submission								

Fig. 2. Work Plan and Time schedule of activities - Bar diagram

4.2 Instruments Required for proposed work:

a) Basic instruments for characterization of various ingredients like fineness and particle size distribution.

b) Le-Chatelier apparatus, CTM, Vicat apparatus and XRF etc., for analysis of the physical properties like soundness, compressive strength, consistency, setting time and chemical composition.

c) Basic instruments for the determination of compressive strength, flexural strength and split tensile strength, Load-carrying capacity, flexural and shear behaviour, bond

strength between reinforcement and UHPC, and the influence of different reinforcement configurations.

d) Use of Ultrasonic Pulse Velocity tester and Rebound Hammer to find the relative strength.
e) Spectrophotometric instruments such as XRD/ SEM etc. for the detailed Mortar Studies.

Proposed Place of work:

Abhilashi University, Chailchowk

CHAPTER-5

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